Exploring Advanced Tokamak Operating Regimes Using Comprehensive GYRO Gyrokinetic Simulations
and
Interaction of ETG and ITG/TEM Gyrokinetic Turbulence

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First NCCS Users Meeting

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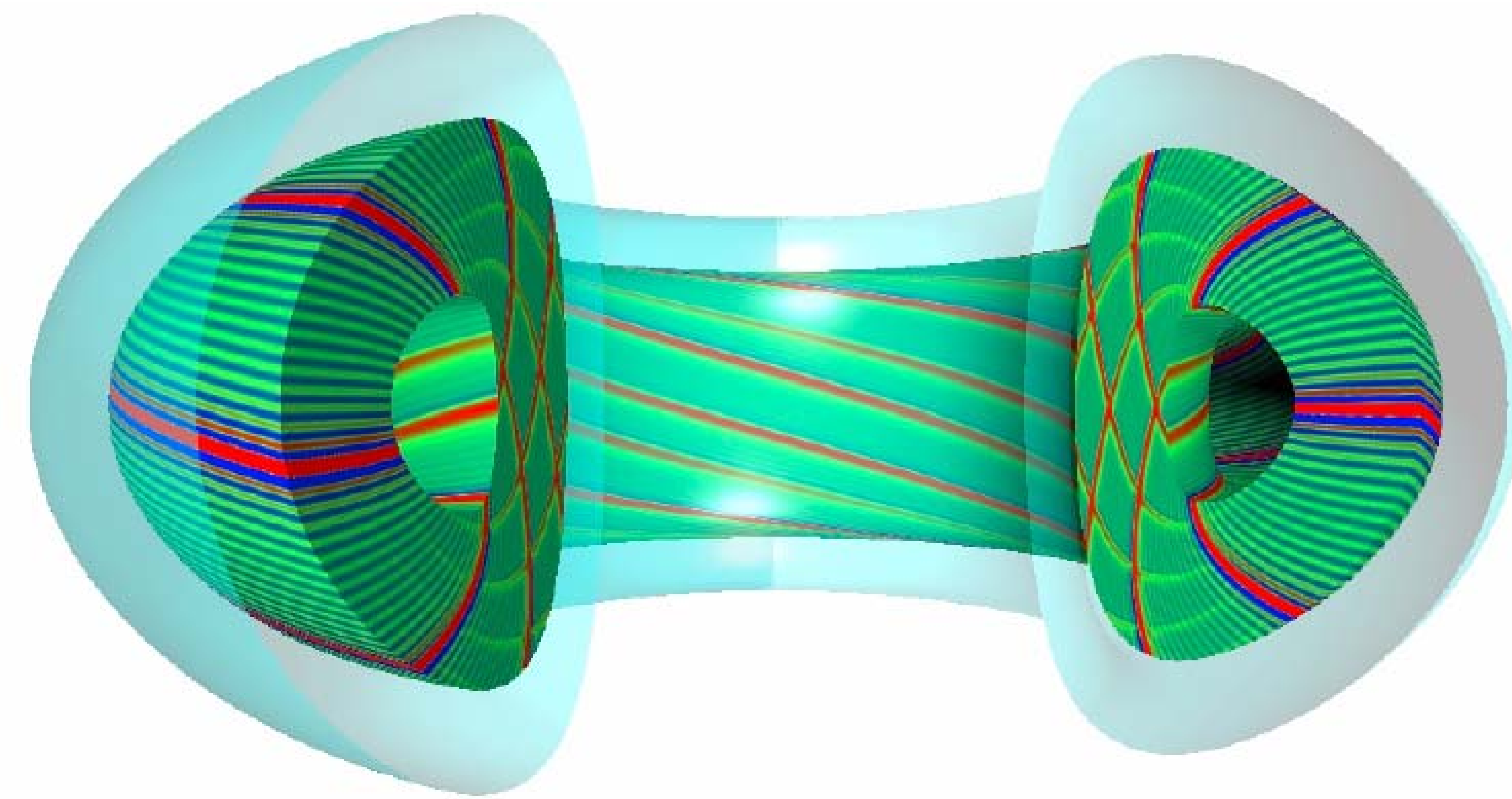
ITG turbulence in shaped plasma - linear phase



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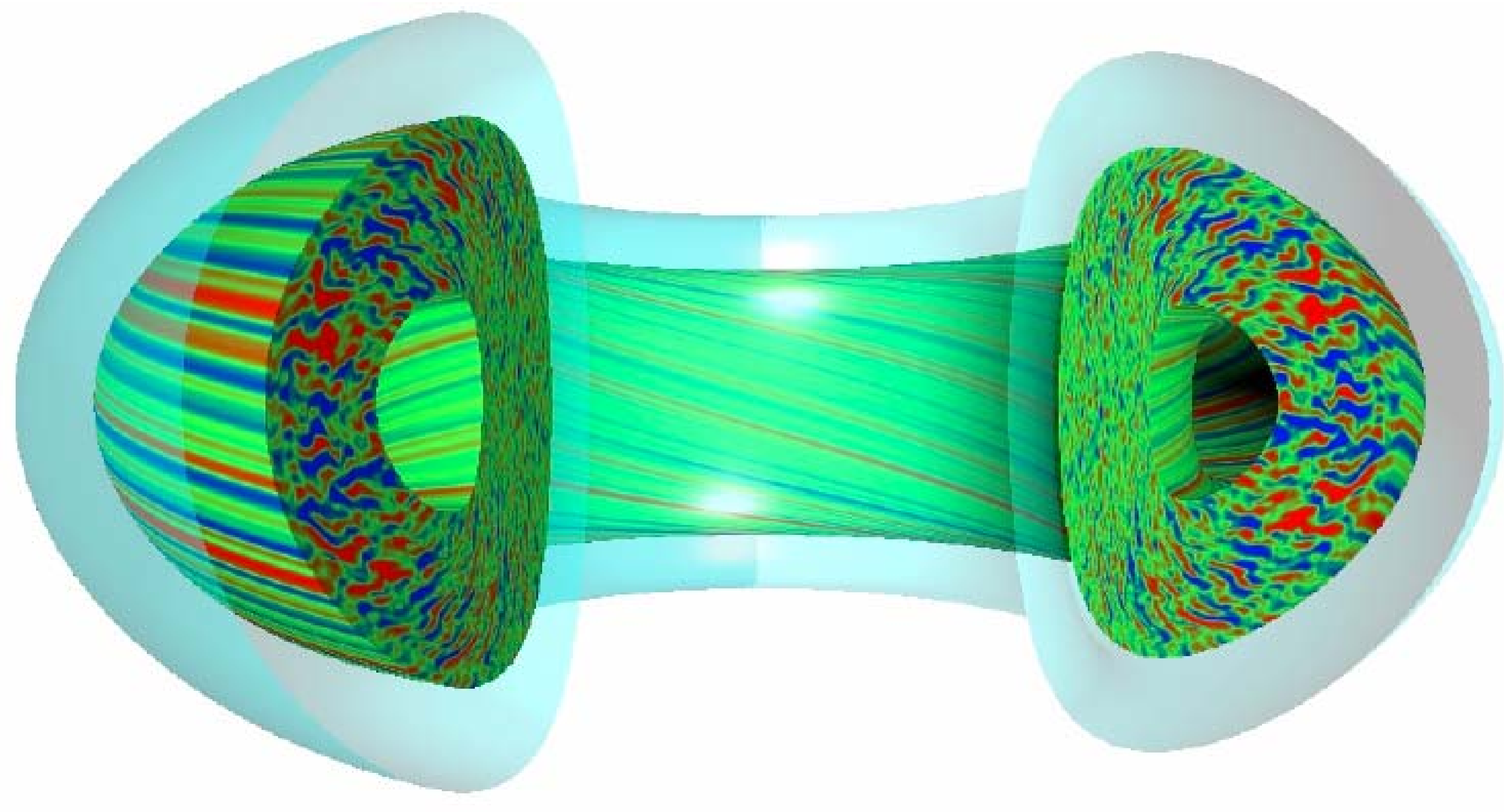


GYRO Code

- GYRO contains all the relevant physics modules for comprehensive tokamak turbulence simulations.
- GYRO is a very portable code, and one of the early application codes ported to, and working efficiently on, the Cray X1E and XT3 at ORNL.
  - Runs on seaborg, cheetah, jacquard, ram, phoenix, jaguar, local clusters
  - Works with PG, Intel, IBM, G95, LF
- Large user base
  - J. Candy, R.E. Waltz and G. Staebler (General Atomics)
  - R. Bravenec (U. Texas)
  - R. Budny and D. Mikkelsen (PPPL)
  - J. Kinsey (GA-Lehigh U)
  - C. Estrada-Mila and C. Holland (UCSD)
  - A. White, T. Carter, E. Wang and G. Plunk (UCLA)
  - C. Bourdelle (CEA-France)
  - D. Ernst and B. Bose (MIT)

GYRO code (cont.)

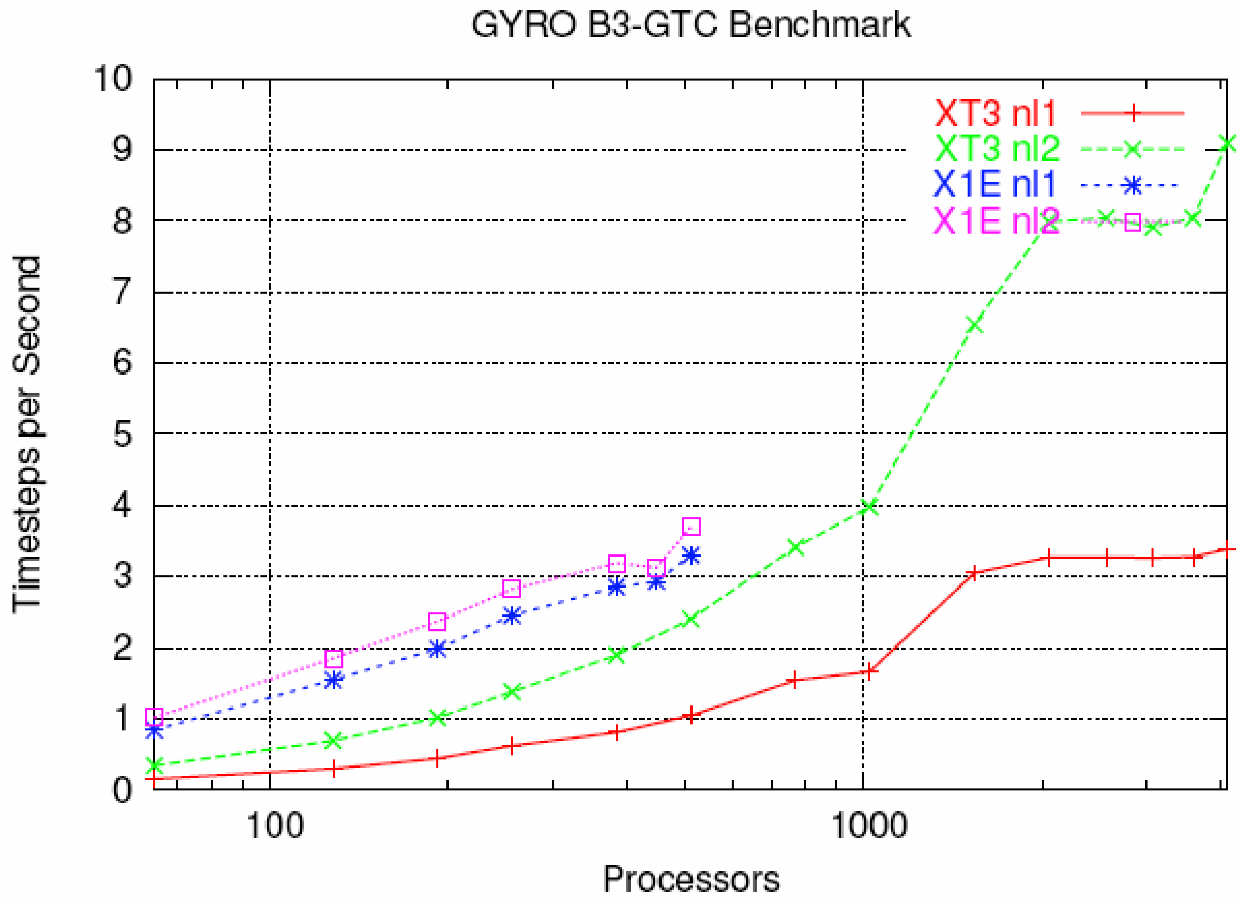
- Physics capabilities by 2002:
  - gyrokinetic ions (electrons) for ITG (ETG) physics
  - trapped and passing electrons for ITG/TEM physics
  - electron-ion pitch-angle collisions
  - finite beta fluctuations and associated transport
  - shaped plasma geometry
  - equilibrium parallel velocity shear for Kelvin-Helmholtz drive
  - equilibrium ExB shear (strongly stabilizing in DIII-D)
  - finite-rho_star effects (profile shear stabilization, nonlocal transport)
  - input of actual experimental profiles
  - particle, momentum and energy flow diagnostics for both electrons and ions

GYRO code (cont.)

- Physics capabilities added since 2003:
  - nonlinear gyrokinetic impurities and associated transport physics,
  - neoclassical physics with ion-ion collision operator ,
  - a profile feedback algorithm for simulating transport at fixed power flow,
  - diagnostic for the neoclassical current-voltage relation with a dynamo EMF,
  - optimizations for fully-coupled, fully-gyrokinetic ITG-ETG simulations

GYRO code (cont.)

- Recent performance plot (with new distribution scheme and scalar optimizations) version 4.0.4



LCF Project

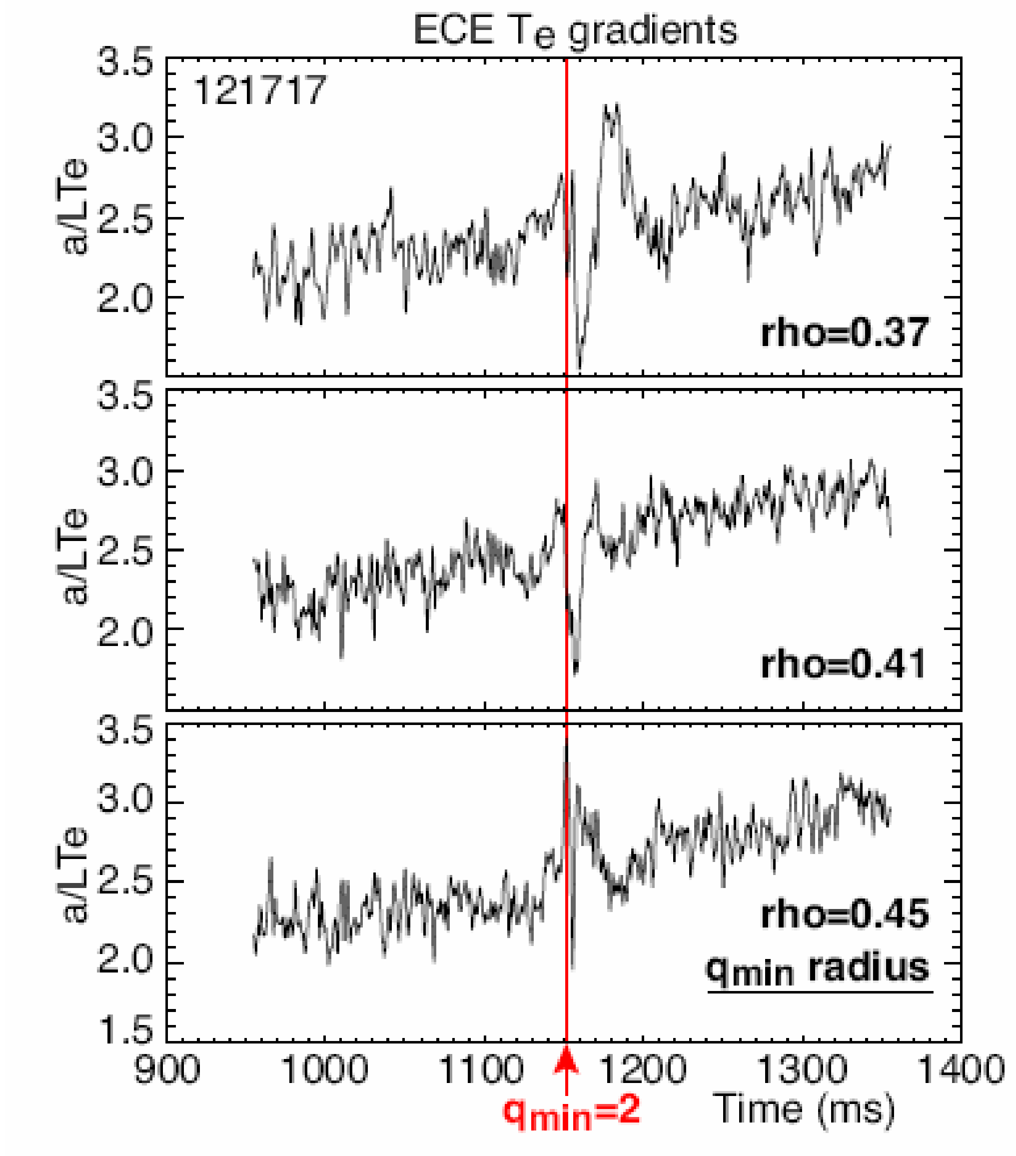
- Exploring Advanced Tokamak Operating Regimes Using Comprehensive GYRO Gyrokinetic Simulations
- PI: Jeff Candy
- 440,240 hours on X1E
- Team:
  - R. Budny, Waltz, Kinsey, Bravenec, Bourdelle, Mikkelsen, Estrada-Mila

LCF Project (cont.)

- The overall goal of this project is to make various detailed nonlinear gyrokinetic simulations which target specific transport-related phenomena in tokamak plasmas
- Project has five research subtopics, with each subtopic addressed by a specific modeling team. The subtopics are
  - transport at $q_{min}=3/2,2$ and electromagnetic effects at rational surfaces;
  - Understanding transport and density fluctuations in C-Mod, JET, NSTX and JT-60U;
  - gyrokinetic edge turbulence;
  - nonlocal effects in HYBRID discharges;
  - energetic impurity transport and ash removal.

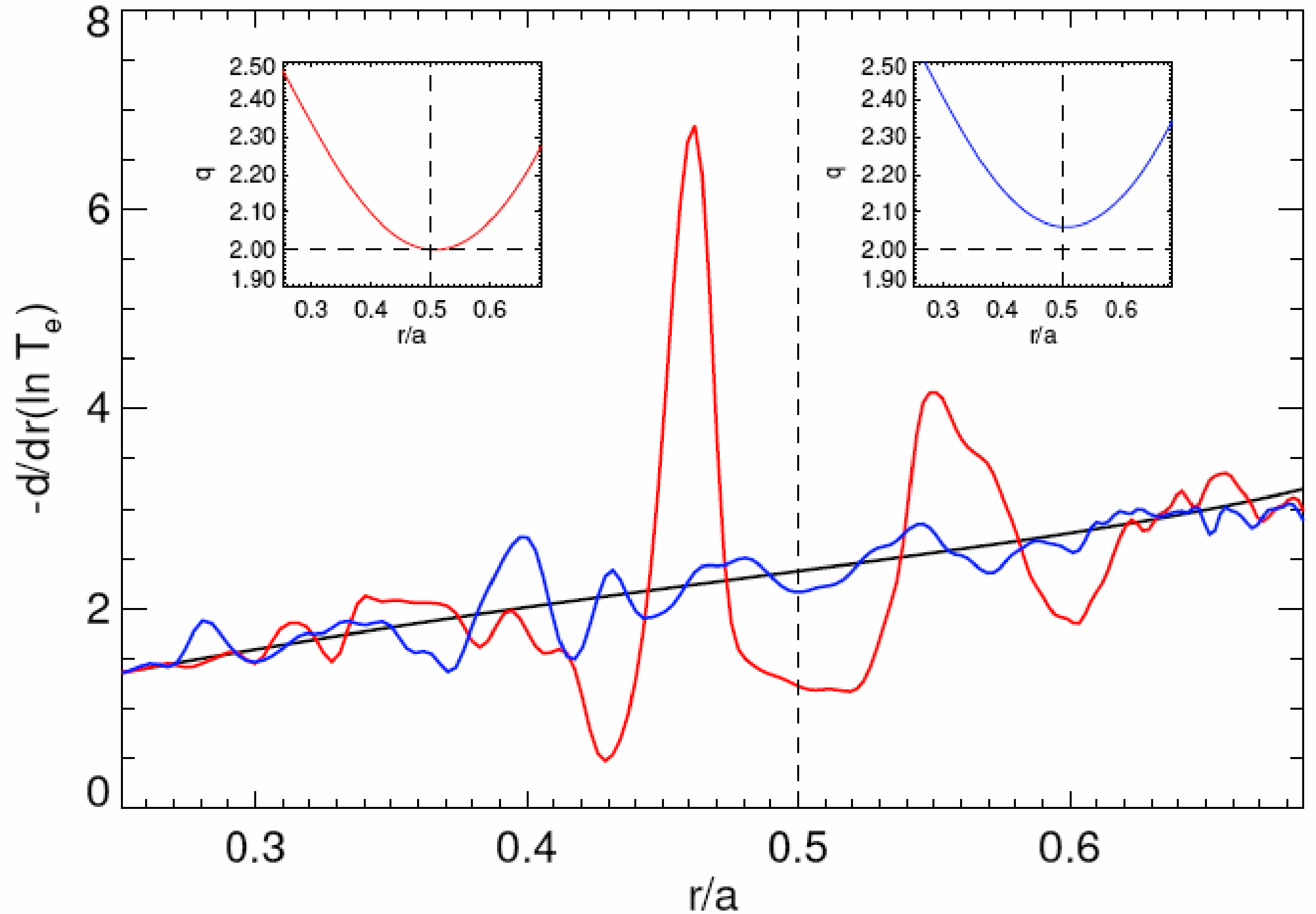
Initial work on LCF project

- Electron Temperature Gradient Spike in DIII-D Experiment
- Appears at q=2; may trigger transport barrier (courtesy Max Austin)
- DIII-D experimental data (at three radii, r/a=0.37,0.41,0.45)
- The time trace indicates a sharp spatial gradient in moving inward as the q-profile drops below unity



Initial work on LCF project (cont.)

- Simulation of q-min DIII-D discharges; GA-A25309 January 2006
- blue trace (just before q drops below 2), red trace (q hits 2). At the moment that q hits 2, GYRO predicts the same electron temperature gradient spike



INCITE Project

- Interaction of ETG and ITG/TEM Gyrokinetic Turbulence
- PI: Ron Waltz
- 400,000 hours on X1E
- **Research Summary:**
  - This proposal will study the computational modeling of the interaction of turbulence on ion and electron spatial and temporal scales. These scales differ by orders of magnitude and have traditionally been treated by separate simulations. The modeling and understanding of plasma turbulence is crucial for the development of stable and efficient fusion devices.

INCITE Project (cont.)

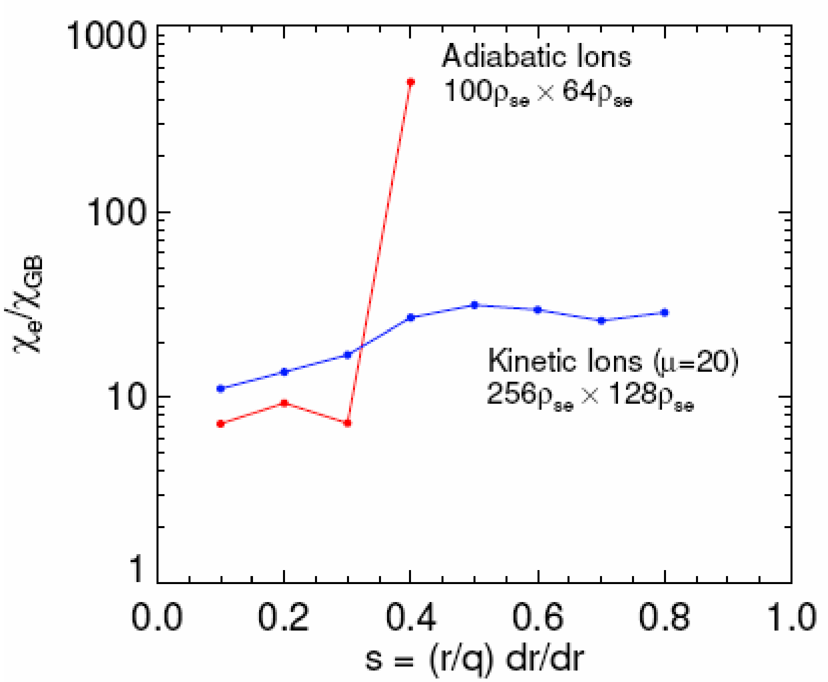
- **Relevance to DOE Mission:**
  - This proposal strongly supports the Office of Science Mission 3.2, “Develop a fundamental understanding of plasma behavior sufficient to provide a reliable predictive capability for fusion energy systems.” For successful operation of the ITER tokamak, a thorough understanding of the H-mode pedestal (an edge transport barrier) is vital. The proposed project could shed new light on how short-wavelength ETC turbulence comes into play as the long-wavelength (ITG/TEM) turbulence is suppressed in the pedestal.

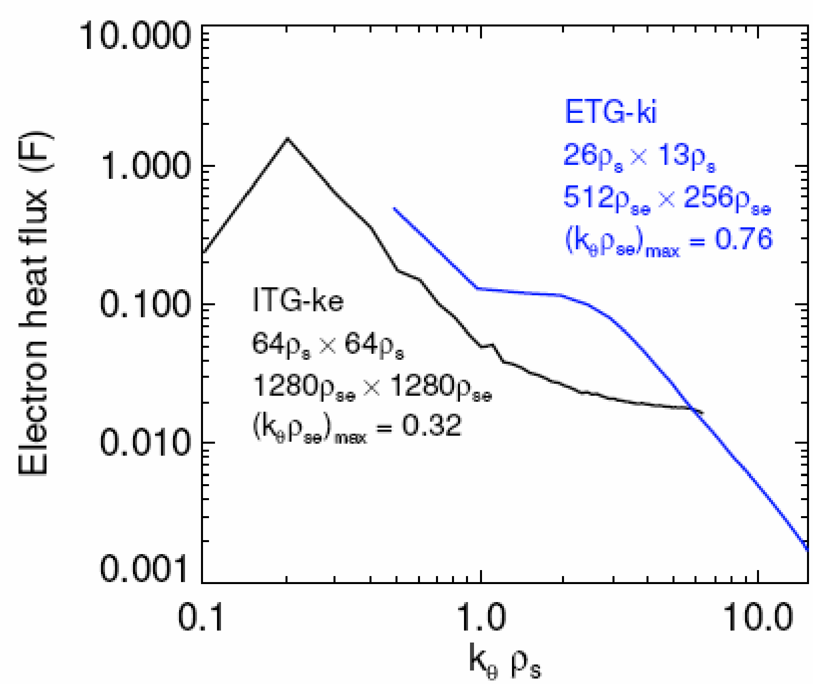
Initial work on INCITE project

- Coupled ETG-ITG Turbulence Simulations
- Nonadiabatic ion dynamics is crucial for saturation!
- The left slide shows that the adiabatic ion model of ETG is bad (the red curve runs off to infinity). On the other hand, the model which includes kinetic ions (much more expensive) saturates and behaves normally. The right slide shows how we can get some spectral overlap in cheap micro (blue) and macro (black) simulations

Cyclone ETG base case with adiabatic electrons does not saturate.

Fully-coupled ITG-ETG simulations (on X1E) saturate properly.





Movies

- c64x64.etg.m20_n.avi:
  - A fully coupled ITG/TEM-ETG version of the Cyclone base case. This shows the electron density fluctuations in a 64 rho_i by 64 rho_i box (1280 rho_e by 1280 rho_e).
- c64x64.noi.m20_phi.avi:
  - same as above, but turning off the ITG instability drive. The full ion kinetic response is, however, fully retained. This is really expensive (same cost as above). The resulting instability is driven by electrons only and the implication is that this is the proper way to run a "traditional ETG' simulation.
- If we use the simplified adiabatic ion response, the case DOES NOT SATURATE